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DIESEL EXHAUST FILTER SYSTEM WITH ELECTRICAL REGENERATION

Field of the invention.

The present invention relates to a diesel exhaust filter system which filters particulate matter and which can be regenerated in an electrical way.

Background of the invention.

Diesel exhaust filter systems, which can be regenerated in an electrical way, are known in the art.

One of the main problems with these systems is that they involve a high degree of electrical power which may cause substantial charge losses to the vehicle battery and which increases the consumption of fuel.

US-A-5,207,807 solves this problem of high power consumption by a modular concept of these parts of the filter, which need to be electrically regenerated. These filter parts are electrically conductive but are electrically insulated from one another and can be cyclically and selectively supplied with electrical power in order to regenerate them.

The complete filter system, however, is large and not practical to be incorporated in the exhaust system of stationary and non-stationary diesel engines.

Summary of the invention.

It is an object of the present invention to simplify the embodiments of the prior art.

It is another object of the invention to reduce the length of the filter system substantially and to make it a very compact design.

It is also an object of the present invention to minimize the electrical power needed for regeneration.

It is also an object of the invention to realize homogenous temperature during the regeneration cycle to eliminate the risk of hot spots and consequently extending the life.

It is yet another object of the present invention to provide a very compact all in one diesel exhaust system addressing the noise, the particulate matter and all other polluting organic fractions such as HC,CO and NO_x present in the diesel exhaust gases aiming maximum performance within a minimum design envelop resulting in lowest possible weight.

It is another object of the present invention not only filtering the heavy particles in the diesel exhaust gases but also for filtration of the small particles.

It is an object of the present invention to include the catalytic function downstream the filter strips in the same design.

According to the invention, there is provided a diesel exhaust filter system which comprises :

- a carrier in the form of a tube or alike, the carrier has radially permeable parts ;
- one or more porous filter strips, these strips are electrically conductive and are wrapped helically around the carrier in a number of windings (each winding being a 360° revolution around the carrier), the windings are do not touch each other, they are laterally separated from each other and cover the radially permeable parts ;
- insulation means to electrically insulate the windings from each other. These electrical insulation means may also thermally insulate the windings from each other.

By wrapping the filter strips around the carrier, longer filter strips can be used while the overall dimensions of the filter are reduced.

In a suitable embodiment the carrier is a tube such as a stainless steel tube having perforations to make the carrier radially permeable.

In another embodiment the carrier can also be a tube made of a highly porous sintered metal fiber medium.

Preferably the filter strips are sintered stainless metal fiber strips made of a stainless steel which is both heat resistant and corrosion resistant. Such stainless steels are known in the art and comprise suitable amounts of chromium, aluminium, yttrium ... An example of composition is between 15 and 22 weight per cent chromium, between 4 and 5.2 weight per cent aluminium, between 0.05 and 0.5 weight per cent yttrium, between 0.2 and 0.4 weight per cent silicon and less than 0.03 per cent carbon.

The advantages of these metal fiber strips is that they have a high degree of porosity combined with a small filter rating and a very low thermal mass made of a high temperature resistant stainless steel alloy. The filter media used is marketed under the registered trademark of BEKIPOR®. The high degree of porosity reduces the backpressure to a very minimum and safeguards in this way the functioning of the diesel engine. The small filter rating safeguards capturing most of the particulate matter including the small ones. The low thermal mass safeguards fast response to reach the required temperature in a minimum of time, requiring a low amount of electrical power.

The amount of fiber used is a determining factor for the required electrical power to regenerate. A smaller amount of fiber could be compensated by smaller diameter fiber to maintain filter rating and dirt holding capacity.

Typical ranges for the metal fiber diameters useful for diesel exhaust filters are between 12 micrometer and 22 micrometer.

In an embodiment of the invention, an inorganic porous fabric in the form of a sleeve is placed between the carrier and the filter strips and functions as electrical and thermal insulating layer between the filter strips and the carrier. Such inorganic porous fabric must be electrically insulating, thermally insulating and resistant against high temperatures.

Another function of the inorganic porous fabric is to seal the filter strips at their border. A suitable example is a cloth braided from silicon carbide, quartz, aluminosilicate or borosilicate fiber tows. On or more sleeves may be provided one above the other.

In an alternative embodiment of the invention, a porous layer of aluminiumoxide, e.g. sputtered on the carrier, functions as electrical insulating layer between the filter strips and the carrier.

In a preferable embodiment of the invention, a wire is wrapped and fixed, e.g. welded, to the carrier in order to keep adjacent windings of the filter strips separated from each other.
Arranging a spring around the carrier may provide an alternative. Preferably the spring diameter is smaller than the diameter of the carrier so that the spring exerts a pressure on the carrier.

One or more inorganic porous fabrics in the form of sleeves cover the filter strips for good thermal insulation safeguarding low electrical consumption.

The system according to the invention further comprises electrical contacts attached at one end of the filter strips. These contacts enable electrical power to be supplied to the strips in order to regenerate them. In contrast with the filter strips, these contacts must have an electrical resistance, which is as small as possible since it is of no use to heat up the contacts during regeneration. In order to lower the electrical contact resistance, these contacts comprise a steel wire mesh, which is sintered to the filter strips and to an electrical conductor. A lightweight wire mesh sandwiched between two layers of fiber is advantageous to enhance uniform temperature avoiding hot spots during regeneration and extend life. Another advantage of the wire mesh is the possibility to custom tailor the electrical resistivity without altering the filter rating.

The principle of using a metal mesh to lower the electrical resistance of the contacts with a strip is not limited to the present invention of diesel exhaust filters made of helically wound strips and can be extended to other metal fiber strips where electrical regeneration or electrical heating is required.

Another metal fiber medium may be added to the system. Having regard to the relatively high external surface provided by the individual metal fibers in this metal fiber medium and to the open matrix structure of a metal fiber medium, the added metal fiber medium of the diesel exhaust filter system, or of the carrier if this is made of a sintered metal fiber medium, can function as a substrate for a catalytic converter to reduce the soluble organic fractions as HC, CO and NO_x in the diesel exhaust gases.

Instead of adding another metal fiber medium to the system, the metal fiber strips which function as filters for particulate matter, may also function as substrate for a catalytic converter.

Preferably, the catalytic reduction of the gases occurs at a second separate upstream or downstream module, while the first downstream or upstream module functions as a particle trap.
The added metal fiber medium, or as the case may be, the carrier of sintered metal fiber medium, is not regenerated, since this risks to burn the catalysts.

In another improvement, the diesel exhaust system comprises an upstream electrode to ionize fine particulate matter particles present in the diesel exhaust gas so that the filter strips catch even fine particles. As a first example hereof, the fine particles are electrically loaded and are caught by the filter strips, which are also electrically loaded.

In a second example, the fine particles are electrically loaded so that they conglobe together to form thicker particles so that they can be caught by the filter strips.

Yet another advantage of the present invention is that it considerably reduces the noise generated from the combustion of the diesel engine. This noise reduction is even of such a degree that muffler is no longer required.

Brief description of the drawings.

The invention will now be described into more detail with reference to the accompanying drawings wherein

- FIGURE 1 schematically illustrates a principal part of a diesel exhaust filter system according to the invention ;
- FIGURE 2 illustrates how an electrical contact can be made between a filter strip and an electrical conductor ;
- FIGURE 3 gives a global view of a diesel exhaust filter system according to the invention.

Description of the preferred embodiments of the invention.

FIGURE 1 illustrates a carrier 10 in the form of a stainless steel tube provided with perforations 12 which are spread over a zone 14 which extends in a helical way in different windings over the carrier 10. A steel wire 16 in the form of a helix is fixed, e.g. welded, to the carrier 10. A porous ceramic fabric 18, e.g. made of braided silica tows and in the form of a sleeve, is put over the carrier and the wire. A filter strip 20 of a sintered metal fiber fabric is wrapped helically over the carrier so that it covers the perforated zone 14 and forms a number of windings (each winding = 360° revolution). The windings are laterally separated from each other. The function of porous fabric 18 is to electrically insulate

and to thermally insulate the carrier 10 (and the steel wire 16) from filter strip(s) 20. The steel wire 16 prevents adjacent windings of the filter strip from contacting each other and/or from moving towards each other. In addition, a second porous ceramic fabric 21 (only partially shown on FIGURE 1) in the form of a sleeve covers the filter element in order to limit the thermal losses during regeneration, and as a consequence to further limit the electrical power required for regeneration. If required for obtaining a good thermal insulation, several layers of ceramic fabric may be provided. Ceramic fabric 21 functions as a thermal insulation.

The carrier 10, the steel wire 12, the porous fabric 18, metal fiber filter strip 20 and porous fabric 21 form a composite filter tube 22.

Typical dimensions for a metal fiber filter strip 20 are :
- width = 31.75 mm (1.25")
- length = 1016 mm (40")
- thickness = 1 mm

Examples of electrical values are :
- resistance R = 0.600 Ohm
- voltage V = 58 Volt
- current I = 19 Ampère
- average power consumption : P = 0.75 kiloWatt (average = over a period of time) ; fuel penalty (i.e. additional fuel consumption due to additional required power) is limited to 1.5%
- regeneration time needed per filter element is less than one minute.

More generally, the above values may range in the following way :
- width : from 10 mm to 50 mm ;
- length : from 500 mm to 1500 mm ;
- thickness : from 0.4 mm to 1.3 mm ;
- resistance : 0.6 Ohm to 5.0 Ohm ;
- voltage : 12 Volt to 70 Volt ;

- current : 5 Ampère to 100 Ampère.

Such a composite filter tube 22 is relatively compact in design and has only a low pressure drop. A second similar filter tube can be put in series to reduce the finest particles in a second phase to reach higher filter efficiencies up to 99% and higher.

In an alternative embodiment, the stainless steel tube is provided with perforations over the whole surface of its casing. A flat wire is helically wrapped around the tube and creates in this way helical zones with perforations between the windings of the flat wire. The filter strips are then wrapped between the windings of the flat wire.

More than one layer of filter strips 20 can be wrapped on the carrier, one above the other, but each layer is preferably separated from the previous one by means of an insulating porous fabric.

At the end of metal fiber filter strip 20 a metal mesh may be sintered to it, in order to realize an electrical contact of reduced resistance with an electrical conductor.
Connecting an electrical conductor to a metal fiber filter strip is not straightforward having regard to the small thermal mass of the filter strip. The filter strips risks to be burned in case of welding. Sintering an electrical conductor together with a metal mesh 24 to the filter strip has proven to provide an adequate solution. Preferably the metal mesh is made of a highly conducting material which can be sintered to the filter strip. An example of such a material is a nickel-chromium alloy. NiCr has an electrical resistivity of 112 micro ohm/K. Copper and aluminium meshes, although having a high electrical conductivity, are not suitable to be sintered.

FIGURE 2 illustrates in detail another embodiment to obtain a good electrical contact at the end of the metal fiber filter strips 20.
The following layered structure is obtained :

- a metal fiber strip 20 ;
- a metal mesh 24 ;
- an electrical conductor 26 where, e.g. the ends of the composing filaments present flare to increase the contact surface ;
- a metal mesh 24 ;
- a metal fiber strip 20.

The parts of the two metal meshes 24, which are sticking out of the layered structure, are bent over 180 degrees one on top and one on the bottom. Extra weight is placed on the edges of the layered structure and the whole is then sintered together.
As explained above, the realization of such an electrical contact is not limited to the present invention.

FIGURE 3 gives a global view of the functioning of a diesel exhaust filter system according to the invention.
The system has two or more parallel modules 28, 30, according to the size of the engine. In the case of FIGURE 3, module 30 is in operation, i.e. functions as a filter, and module 28 is switched in an off-line status and can be regenerated. So regeneration occurs off-line, i.e. when the module is not in operation.
The exhaust gases follow the direction of the arrows. Pipings 32 conduct the dirty exhaust gases from the exit of the diesel engine 34 to filter modules 28 and 30. Exit pipings 36 conduct the cleaned exhaust gases from modules 28 and 30 to the environment. Each module 28, 30 can be provided with one or more composite filter tubes 22 as illustrated in FIGURE 1.
Exit pipings 36 can be provided with valves 38 and 40. In the case of FIGURE 3, valve 38 closes module 28 so that this module becomes off-line and that this module can be electrically regenerated. Valve 40

leaves module 30 in operation so that nothing prevents the diesel engine from continuing to operate.

As filtering proceeds, the pressure drop over the composite filter tubes becomes greater and greater. This drop can be monitored and once a certain level passed for one or another module, the module can be switched off-line to regenerate. In this way regeneration is only done when necessary and electrical power is used in an efficient way.

The diesel exhaust system can also be equipped with one or more electrodes 42, which charge electrostatically any fine particles present in the exhaust gases. The filter strips 20 themselves can also be charged electrically and may function as a precipitation electrode to hold the fine particles. During the regeneration phase the filter strips are heated above the ignition temperature of the fine particles so that these are removed. Such a system for removing fine particles is disclosed in EP-B1-0 650 551.